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MATERIALS AND FABRICATION PROBLEMS ASSOCIATED WITH MORAY

(U)

by

Richard J. DeMarco
Weapons Development Department

ABSTRACT. To establish the feasibility of a small, two-man deep-diving submersible, a test vehicle, Moray TV-1A, was designed and constructed at the Naval Ordnance Test Station in collaboration with the Navy West Coast Group for antisubmarine warfare (ASW). This free-moving man-monitored research vehicle is currently undergoing evaluation tests to determine performance characteristics. Upon satisfactory completion of these tests, the vehicle will be available for probing problem areas in deep-sea operations and to use as a platform for experimental sonar, communications, television, ordnance, and propulsion units. (UNCLASSIFIED)

U.S. NAVAL ORDNANCE TEST STATION
China Lake, California
April 1963

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

C. BLENMAN, JR., CAPT., USN — Commander
WM. B. MCLEAN, PH.D. — Technical Director

FOREWORD

The development of the research vehicle Moray, a two-man deep-diving submersible, was accomplished at the Naval Ordnance Test Station as part of an over-all exploratory and foundation effort to advance the state-of-the-art in underwater technology.

The design criteria was set forth early in 1960, and incremental construction began shortly thereafter and continued until November 1962 when final assembly was accomplished.

A successful preliminary shallow water test was conducted in December 1962 at this Station in the SNORT reservoir. Additional tests are scheduled at San Clemente Island for early Spring 1963.

This report summarizes a few of the major material and fabrication problems encountered in the construction of the research vehicle Moray. More detailed information may be obtained from the technical documents listed in the references.

This report was reviewed for technical accuracy by C. E. Jenkins and D. L. Jacks.

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LEROY RIGGS, Head,
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INTRODUCTION

The Moray Research Program is aimed at establishing the feasibility of a two-man deep-diving underwater vehicle. This vehicle could have extensive applications. From the very beginning, it was realized that the problems of design and operation of a small deep-sea probe were considerable. Solutions to these problems required construction of a vehicle.

Moray was first conceived as a protective weapon for operation with surface ships. It will now be used to investigate the problems of operating a small, manned vehicle in cooperation with surface craft, as well as to permit for the first time, a free-moving, man-monitored research vehicle for probing the problem areas of deep-sea operations. In the normal sequence of these operations, studies will be initiated to advance the state-of-the-art in many fields. These basic studies will include investigation of acoustic phenomena beneath the thermal layer, optical absorption and light-scattering in deep blue water, radio and sonar communications, high-speed propulsion systems, reactions of materials and components to pressure and maneuvering stresses, and human factors in an isolated environment under fatiguing routine.

BACKGROUND

To establish the feasibility of a small, two-man deep-diving submersible, a test vehicle--Moray TV-1A--was designed and constructed at the Naval Ordnance Test Station (NOTS) in collaboration with the Navy West Coast Group for antisubmarine warfare (ASW).

The requirements imposed upon the structure and subsystems of the deep-diving submersible Moray, by virtue of the deep ocean environment, place severe limitations on the design criteria. The tentative design goals of the Moray vehicle are: an operational depth of 6,000 feet, a test depth of 7,840 feet, an over-all weight of 18,000 pounds dry or 30,000 pounds wet, a diameter not to exceed 64 inches, a length of approximately 35 feet, a velocity of 40 knots, an adaptability as a platform for experimental sonar, television, communications, and ordnance devices, and a compatibility with shipboard handling equipment.

The present Moray TV-1A represents a compromise between these design goals and the desire to rapidly establish the basic conceptual feasibility. Available components and readily fabricated structures were employed in the TV-1A with changes in design goals to an operational depth of 2,000 feet and a velocity of 15 knots, both due to the moderate capabilities of the interim propulsion system.

Since effort was somewhat limited, the nature of the work, by necessity, became more of a study. To optimize the vehicle's capabilities, a greater research effort would be necessary. However, the studies have led to successful applications of new materials as well as improvements in the use of many of the conventional materials.

CONFIGURATION

The David Taylor Model Basin hydrodynamic configuration 4170 was chosen by members of the Moray project in collaboration with the Basin personnel and the Navy West Coast Group for ASW. In powered model tests at the Stevens Institute of Technology, the configuration proved to have excellent dynamic stability.

The exploratory test vehicle Moray TV-1A, constructed at NOTS, incorporated a modified 4170 hull configuration for reasons of ease of fabrication, lower cost, and test program flexibility. The modification entailed a cylindrical section from hull stations 84 to 180, the particular section that houses the instrumentation and personnel sphere, as well as a hemispherical nose from station 52 to 84 (Fig. 1).

The outer hull is "soft", nonpressure resistant, while all the major internal components that are pressure sensitive are protected from ambient pressures by a "hard shell". These components are the personnel and instrumentation spheres, battery compartment, hydraulic control actuators, and propulsion system.

FABRICATION TECHNIQUES

Several unique approaches in design and engineering are being tried in the Moray TV-1A. As an example, Fiberglas was selected for the flooded hull material because of its ease of fabrication, relative strength, durability, and resistance to the sea water environment. Also, a NOTS-developed syntactic foam was incorporated into the vehicle to provide the necessary over-all positive buoyancy, a basic precept of the Moray TV-1A design.

The personnel and instrumentation spheres were fabricated from cast aluminum A356-T6 which permitted, by means of removable inserts in a single pattern, all the variations necessary for the upper and lower hemispheres, with their particular reinforced areas and openings.

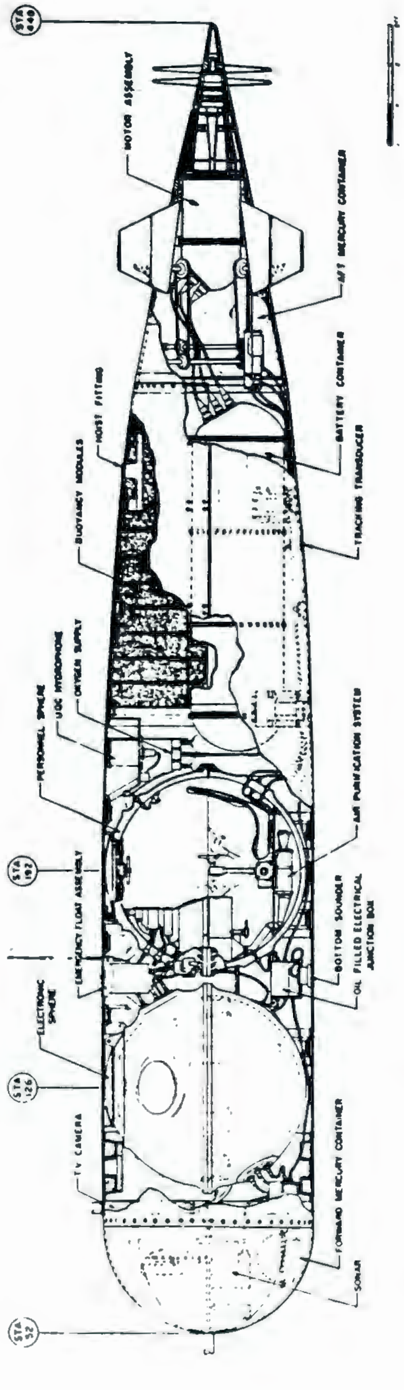

FIG. 1. Moray TV-1A Configuration.

The problems associated with the aforementioned components of Moray TV-1A were similar to those of all the other components, with the exception of the limited choice of materials available to meet the design criteria. An additional problem, once a suitable material was chosen, was the inexperience in fabrication techniques associated with the large amount of material required. In preliminary laboratory production of the various materials, the physical properties met the required specifications, but when pilot productions were initiated, extreme care and quality control had to be exercised to assure adherence to the rigid specifications.

To elaborate on the particular solutions to the problems outlined above, each of the three components will be discussed separately, briefly setting forth background, material considerations, operational problems, technical problems, and conclusions.

MORAY TV-1A HULL

The hull is a laminated structure of woven glass fabric Volan 1000-150 and Dion-Isothalic 6630 resin, according to military specifications MIL-P-17544C (Ships) and MIL-P-8013C. This material was chosen upon consultation with leading fabricators in the plastics industry. Specific information on a deep-running unmanned sonar platform, constructed by the Zenith Plastics Company for the Telephonics Corporation, was invaluable in providing preliminary test data of the mechanical and physical properties of a suitable plastic laminate.

The waterframe for the Moray TV-1A is of semi-monocoque construction composed of an outer faired skin, designed to carry shear and bending loads. The skin is reinforced at approximately three-foot intervals by laminated, hat-sectioned frames. These frames help to maintain the shape of the hull, and also serve to distribute concentrated loads from the hoist fittings, spheres, battery case, etc., to the hull skin (Fig. 2).

The forward and aft portions of the vehicle are removable at hull stations 84.4 and 340.0, respectively, while the hull between these stations is characterized by a separation along the horizontal centerline which allows the upper half of the hull to be removed for maximum accessibility to the components. Bolted frame splices provide structural continuity across the horizontal centerline joint. The structural strength requirements are written in terms of limit and ultimate loads. Limit loads are the maximum anticipated service loads, while ultimate loads are the limit loads multiplied by a factor of safety. A minimum factor of safety of 1.5 was used throughout this design (Ref. 1).

Because the hull (i.e., that portion of the over-all TV-1A configuration between stations 84 and 340) was split along the horizontal mid-line,

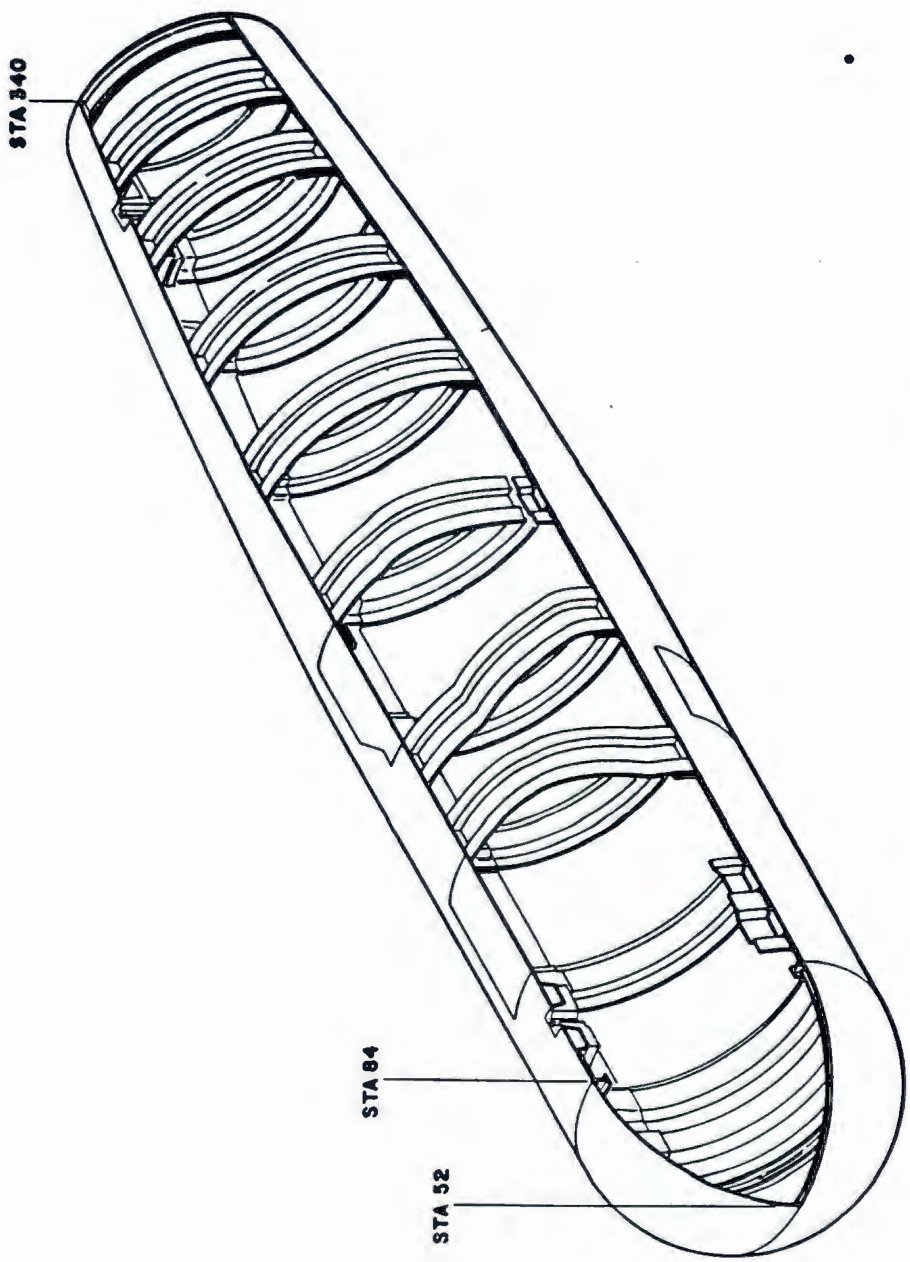

FIG. 2. Structural Cutaway of Moray TV-1A.

a dimensionally accurate plaster mold was formed from which a Fiberglas, polyester resin, honeycombed-reinforced female mold was made. From this single mold, both the upper and lower hull sections were made utilizing a simple hand lay-up technique. The hat-section circumferential stiffeners required a temporary in-hull mold that, when filled with a low density material, would be the inner form of the Fiberglas frame buildup. This proved to be the most practical method of developing a closed frame section on the hull, since any other method which employed a lost wax or soluble plaster buildup would necessitate an open end for core removal, followed by a complex end-closure operation. The low-density material--an epoxy compound composed of 20% phenolic microspheres, 10% inert filler, 70% epoxy resin and hardening agent--has an average density of 40 to 45 lb/ft^3, a compressive strength of 6000 psi, a flexural strength of 2500 psi, and a service temperature up to 250°F. Data of tests conducted at NOTS reveal that at a depth of 2000 feet, it will compress approximately 1.4% resulting in a loss of buoyancy of 2.4 lb, based on a total of 8 cu ft of buoyant material within the nine hull stiffeners.

The hull has a basic thickness of 0.25 inch, increasing to a thickness of 0.30 inch on the upper shell half between hull station 84.0 and hull station 242.0, which eliminates the need of longitudinal stiffeners in this severely loaded region. The hull openings, hatches, flooding ports, access ports, etc., are reinforced with Fiberglas buildups to maintain the structural integrity of the hull.

Since the female mold established the outer configuration of the hull, modifications to the inside surface during the initial fabrication as well as after completion were easily accomplished, since it was only a matter of bonding several layers of resin impregnated Fiberglas cloth in or around specific locations. Care was exercised so as not to apply too large a buildup at one time, or an exothermic condition would impair the strength of the bond. The exothermic condition caused a delamination in several hull stiffener and closures, but these solid glass buildups were easily corrected by peeling away the unbonded plies and replacing them with new cloth, allowing more time for adequate resin bonding between each ply.

The most serious problem encountered in the fabrication of the hull was during the post-cure operation. Similar to the technique of heat treating metals, post-curing of certain types of Fiberglas structures will develop better physical properties; however, the Plastics Industry has not determined the shrink rate tables to the same degree as in the Metals Industry. In the post-curing operation, the polyester resin reaction caused a hull close-in at the horizontal centerline of each half shell. Fortunately, with slight modifications of interior components and the use of permanent spreader bars fore and aft, a workable compromise was attained.

The method of securing both half shells together employs 164 semi-permanent and 164 removable 100-deg flat-type socket-head screws made of 316 stainless steel per Federal Specification QQ-S-763b(2), condition A.

As a final precaution, the hull was coated on the inside with an epoxy resin; and to aid in underwater visibility, the exterior was coated with white and black epoxy paint.

BUOYANCY MATERIAL

A basic precept of the Moray TV-1A design is that the vehicle be positively buoyant at all times. Weight and balance estimates indicated that the hull, with its components, would have a net negative buoyancy and a center of gravity too far aft of the center of buoyancy. It was necessary to incorporate a low-density material in the after-section of the vehicle to compensate for the buoyancy deficit and trim. Accordingly, in June 1960 a low-density-material data collection and measurement program was initiated. The results of the program are the subject of a NOTS Technical Report, (Ref. 2).

The buoyancy problem imposed material restrictions which could only be overcome if the material possessed high compressive strength, an absolute minimum of water absorption, relative ease of fabrication to permit free forming to fill the non-uniform spaces, and an insensitivity to shock loads.

The only material to meet all the basic requirements of Moray TV-1A was a syntactic foam; i.e., a foam in which the density and other physical properties are controlled by the percentage of lightweight filler used in the formulation.

The particular formulation for the NOTS foam 7-A is as follows:

Epon 815 Epoxy Resin (Mfg. by Shell Chemical Co.), 75.0% by weight

Diethylamino Propylamine Hardener (DEAPA) Epon Curing Agent "A" (Mfg. by various co.), 5.0% by weight

Eccospheres SI Microspheres (Mfg. by Emerson & Cummings, Inc.), 20.0% by weight

The foam has a density of approximately 40.5 lb/ft ^{3} and will lose less than 1.0% of its buoyant force when subjected to a hydrostatic pressure of 1500 psi for a period of 24 hours.

The actual production of the foam is to some extent an art, but fortunately the Station's facilities and experience in the manufacturing of propellants established techniques that were readily adaptable. The temperature-controlled vacuum mixers, used in the production of the polyurethane, nitrasol propellants, maintained the proper pouring viscosity as well as excluded most of the air from the mixture.

The consistency of a mix is governed by the percentage of the S1 microspheres used. A lower density mix may be obtained by the addition of more microspheres, but will result in a mix which cannot readily be poured. If a mix requires additional packing or tamping after being poured into the mold cavity, there will very likely be air included. Heat may be applied to the epoxy to lower its viscosity if pouring conditions warrant such action, but care must be exercised not to create a condition whereby the exotherm will "set" the mix prematurely.

The mixture phase is governed by the quantity being mixed; large quantities will hasten the "setting" time. Complete mixing of quantities of one-half gallon or less presents no problem, but larger quantities may require premixing of microspheres and epoxy resin, followed by a short mix time with the curing agent.

The amount of material poured depends upon the depth of mold cavity; the exotherm will cause "burn areas" if excessively deep sections are cast. The NOTS formulation tended to "burn" when cast in sections exceeding 3 inches. These "burn areas" contain air pockets and thereby reduce the compressive strength of the finished product.

The buoyant material, approximately 50.8 cu ft installed in the upper hull half and 23.7 cu ft installed in the aft aluminum control section, was cast in place utilizing mold release and module separators. The total volume of 74.5 cu ft of buoyant material will provide Moray TV-1A with 350 lb of initial positive buoyancy (Fig. 3).

PERSONNEL AND INSTRUMENTATION SPHERES

In the initial preparation of design data for the Moray TV-1A personnel and instrumentation spheres, all possible forms and materials were considered. After a thorough investigation of design theories for the various geometric forms, the work done at the David Taylor Model Basin was utilized as the basis for the design criteria.

A great deal of effort has been expended in the study of conventional and unconventional pressure-vessel configurations, undergoing external pressure, for maximum depth submersibles. This work and subsequent experiments have contributed significantly in the development of submarines and have been incorporated whenever possible. Unfortunately, the aforementioned work has not been gathered in one publication, but requires a study of many separate reports.

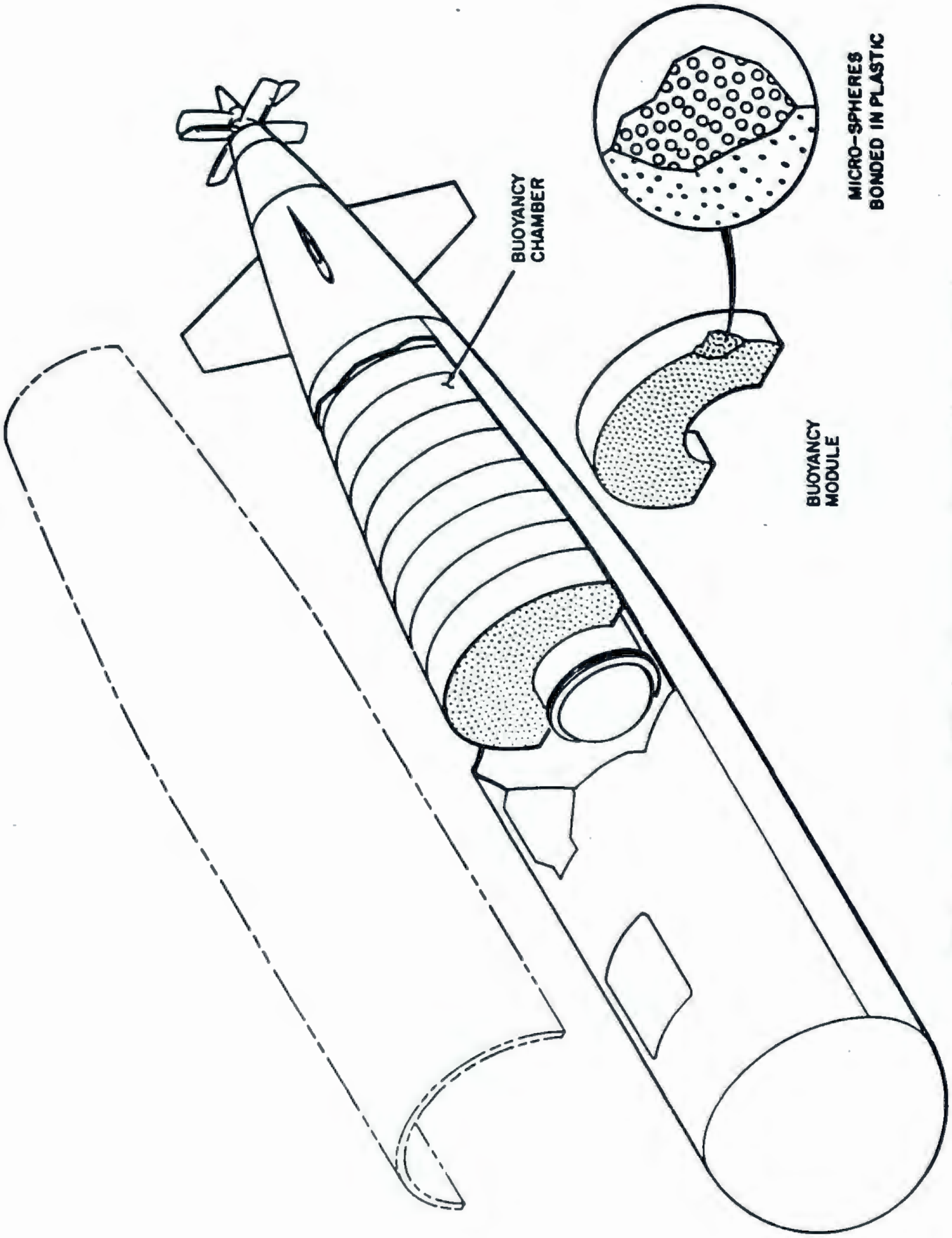

FIG. 3. Moray TV-1A Buoyancy Material Installation.

In light of the conclusions and recommendations of the study made by E. Wenk, Jr. (stated in Ref. 3) and the particular spacial requirements of Moray, a spherical pressure vessel was chosen for the personnel enclosure. It then followed that the limitation imposed upon the sphere by the outer hull configuration, and the necessity for a maximum internal volume, relegated the personnel enclosure to a semithin-walled pressure vessel.

The possible modes of failure of a stiffened spherical shell can be either by elastic instability or yielding, depending upon the thickness of the shell and degree of stiffening. It was desired that the personnel sphere fail under external hydrostatic pressure by yielding of the shell in the nominal wall thickness area when the combined stresses reach the yield point of the material, rather than by buckling, since there are so many uncertainties in the buckling theories for stiffened spheres. The exact theoretical predictions for buckling are known from experimental observations to be unobtainable, and necessitate semi-empirical corrections to the classical formula. Similarly, the external pressure that will cause an unsymmetrical spherical pressure vessel to collapse cannot be accurately predicted by the use of a single formula, since the complexities of openings, pass-throughs, reinforced areas, and secondary structure are not taken into account. After a careful study of materials and heat treating methods, an aluminum alloy A356-T6 was chosen because its physical properties, coupled with a rationalized vessel geometry, optimized the yielding condition, while minimizing the buckling probability. The yielding mode of failure was observed in subsequent scaled model experiments. The strength of the pressure vessel depends principally upon the compressive yield strength of the material and thickness-to-diameter ratio, t/D. With the aforementioned parameters, the yield pressure can be predicted by the membrane equation $P = 2t\sigma y/r_o$ or the A.S.M.E. code formula for hemispherical heads under internal pressure $P = 2t\sigma w/r_i$, by substituting the yield strength σy for the allowable working stress σw, and the outside radius of the sphere r_o for the inside radius of the sphere r_i. The thickness, t, in both equations is that of the nominal wall.

In addition to the previous design criteria, the relationship of the structural weight to displacement was considered an index of utility because positive buoyancy is a prime factor in the operation of an underwater vehicle. This relegated the investigation of the materials to the following: aluminum, magnesium, titanium, and reinforced plastic laminates. The mechanical properties of these materials are shown in Table 1.

MODEL TESTS

Notwithstanding the care with which various modes of failure of stiffened shells have been investigated, there remains a strong desire

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TABLE 1. Mechanical Properties of Structural Materials

Material	Tensile yield, psi x 10^3	Tensile ultimate, psi x 10^3	Compressive yield, psi x 10^3	Young's modulus psi x 10^6	Elongation, percent	Density, lb/in^3	Condition
Aluminum							
2024-T4	38-46	60-65	38	10.6	20	0.100	Heat-treated
A356-T61	30-35	41-45	32-42.2	10.3	10	0.097	Heat-treated
6061-T6	35	42	36	10.1	8	0.096	Heat-treated
7075-T6	60-72	75-80	63	10.5	4	0.101	Heat-treated
Magnesium							
AZ80A-T51	33	48	35	6.5	4	0.064	Heat-treated
AM100A-T6	17	32-37	approx. 17	6.5	not req'd	0.064	Heat-treated
ZK61A-T6	25	38-40	approx. 25	6.5	5	0.064	Heat-treated
ZK60A-T5	36	45	36	6.5	4	0.064	Heat-treated
Titanium							
6Al-4V	120	130	120	15.8	10	0.160	Annealed
6Al-4V	160	180	160	15.8	10	0.160	Heat-treated
B-120-VCA	170	190	170	15.8	6	0.162	Heat-treated
MST-821	130	138	139	17.4	20	0.162	Annealed
C-120AV	120	150	120	15.8	10	0.160	Heat-treated
A-110AT	110	115	approx. 110	16-18	10	0.161	Annealed
Glass Fabric Reinforced plastic	30.1 standard 28.5 wet	37 (edgewise)	26.8 standard 23.8 wet (ultimate strength)	1.69	---	0.071	---

to confirm the strength of each design. Historically, this has been accomplished through the tests of small-scale models. Such models are fabricated as geometrically similar as possible to the initial prototype design. From dimensional analysis, it can be shown that the hydrostatic pressure at which failure occurs in a full-scale structure can be predicted from pressure at which the failure occurs in a geometrically similar model on a 1:1 ratio. There is, however, the prerequisite that perfect geometric similitude be obtained. This means that imperfections in the model must be appropriately scaled. Also, it is necessary that the yield strength of material in the model be identical to the yield strength of that in the prototype (Ref. 3).

The Bureau of Ships felt the need some time ago to confirm the validity of such small-scale replicas in prediction of submarine strength. Full-scale tests failed at pressures within 5 percent of those predicted by the small-scale replicas. This is an exceptionally close agreement, considering all of the differences in the yield strengths of materials and imperfections in workmanship that occur (Ref. 3).

To confirm the strength of the control sphere, an intensive model study was undertaken, utilizing the hydrostatic test facilities at NOTS. The nature of the study and results are the subject of NOTS Underwater Weapon Systems Branch Memorandums (Ref. 4 through 8).

DESIGN CRITERIA OF SPHERES

The design criteria for the personnel and instrumentation spheres are as follows:

1. Maximum Depth. The maximum test depth is 7840 feet or 3500 psi and the maximum operating depth is 6000 feet or 2680 psi.

2. Buoyancy. The buoyancy is approximately 2000 lb, based on the following parameters:

   a. Displacement of assembled sphere, 68.2 cu ft or 4379 lb of water.

   b. Weight of assembled spheres, 2366 lb.

3. Low Corrosion Susceptibility. Material used in construction of spheres is a cast aluminum-alloy type A356-T61 that has a relative rating of good corrosion-wise. This was improved by a brush Alodine, chemical conversion coating per MIL-C-5541, followed by several coats of zinc chromate. Materials used for pass-throughs, attachments, brackets, bolts, etc., are aluminum alloy 6061-T6 and stainless-steel type 316, 321, and 347. Teflon coatings were used wherever possible to eliminate galvanic problems as well as galling when securing the components.

4. Heat Transfer. The A356-T61 aluminum-alloy has an excellent thermal conductivity of 110 Btu/(hr)(ft^2)(°F)/ft. Good thermal conductivity is essential since the hull is being relied upon to act as a transmission medium to conduct the approximate 4000-Btu/hr heat load to the ocean sink.

5. Pass-Throughs. The passage of high-pressure lines, electric cables, and hydraulic tubes through the pressure hull of the personnel sphere required a compatibility with the ambient sea conditions. This necessitated high-pressure seals, corrosion resistance, and compressive yield strengths adequate to resist the effects of cycling (fatigue). A series of hydrostatic tests were conducted on all pass-throughs. The results of the tests are the subject of Ref. 9 through 11.

6. Hull Reinforcements. The reinforcements for the hatch, pass-throughs, attachments, etc. were based upon design criteria established for the "Trieste" and on information gained through extensive model testing. It was determined that an increase of 1.5 times the nominal wall thickness was adequate for all openings in the sphere. Precise model tests were necessary since reinforcement for the various openings could not be solved by simple uniform wall theory (Ref. 1).

7. Physical Characteristics.

a. Outside diameter, 60.0 ± 0.125 inches.

b. Inside diameter, 56.6 ± 0.125 inches.

c. Wall thickness, 1.70 inches (nominal) +0.250, -0.000

d. Wall thickness, reinforced areas for openings, 2.40 + 0.250 inches, -0.000.

e. Weight of assembled sphere (incl. hatch), 2366.0 lb.

f. Volume of assembled sphere (incl. hatch), 68.22 cu ft.

g. Volume of interior of sphere (sans equipment and personnel), 55.0 cu ft.

8. Hatch.

a. Access opening, minimum diameter of 17.5 inches.

b. Static seal design incorporates both "0" ring and metal-to-metal.

c. Hand wheel operated, multiple-wedge, cam-locking mechanism. Emergency exterior unlatching device provided.

d. Double-torsion spring exerting 1,400 in-lb at 14-inch moment arm to counterbalance the hatch weight through 95-deg movement.

9. Cost. The relative cost of the aluminum castings with respect to titanium or aluminum wrought alloys is a magnitude of 1/10 to 1/4, respectively.

MANUFACTURING PROCEDURE

1. Semipermanent sand mold, employing extensive chilling (cast iron and bronze) in all the critical areas was used. The sand was hardened by carbon dioxide, similar to the techniques used in core preparation. The size of the mold and quantity of metal to be poured necessitated special gates and risers. The gates were designed to cascade the molten metal down into the lower portion of the mold by means of canted baffles or steps to minimize turbulence, which is a major cause of casting defects. Holes were located in critical areas to vent the gases that would otherwise cause excessive porosity, if not an explosion. These holes were later filled by welding. Special crucibles were used to minimize interaction with the molten metal, thus preserving the nominal limits of the chemical composition. Samples of the molten metal were taken (from each of the four furnaces) for test specimens, which in turn were spectrographed for conformity with the A356 limits. After the total melt of approximately 4500 lbs was checked, approved, and brought to the exact pouring temperature, the mold was poured.

2. Quality Specifications and Inspections. The composition of the A356-T61 aluminum alloy was as per MIL-C-21180A Class II, which states that the material shall be such as to produce castings in full compliance with the requirements specified herein.

3. Repair Techniques. All cold shuts, inclusions, cracks, and microporosities were corrected by welding to MIL-W-22248, Class II, after removal of the defective area.

4. Heat-Treat (Ref. 8). The A356 aluminum alloy was solution heat-treated, quenched in water, then artificially aged to a T-61 condition, which was the most desirable combination of strength, hardness, and elongation. The chemical analysis and physical test of the A356 aluminum alloy was conducted by the Metals Control Laboratories, Los Angeles, Calif. The certified data sheets indicated a range in compressive yield strength from 42,200 psi to 34,210 psi. For the Moray application, the actual temperature and time are as follows:

a. Solution heat treat, 1000°F ± 10°F for 12 hours.

b. Quenching in water, 150°F to 212°F (preferably at 212°F).

c. Precipitation heat-treat (artificially aging), 310°F ± 10°F for 6-10 hours.

5. Machining.

a. Vertical mill: establish flange, O-ring grooves, hatch mating surface, etc.

b. Horizontal mill: facing operations, bosses, pads, pass-throughs, hatch hinge pin, etc.

c. Radial drill: bolt holes in flange, counterboring and spotfacing.

CONCLUSIONS

In many applications, the desire to compromise design criteria in order to minimize severe material and fabrication problems results in a reduction of the over-all operational capability. However, when a reasonable amount of time is devoted to studies of the problem, many improvements in the use of conventional materials as well as successful applications of new materials can be realized without undue compromise of initial design goals.

The application of composite Fiberglas, reinforced plastic-laminate structures for deep-submergence hulls appears feasible for depths to 20,000 ft. However, a major problem with the reinforced plastic laminates is quality control.

The use of syntactic foams for buoyant material requirements appears feasible for depths to 6,000 feet, based on preliminary tests conducted at the Naval Ordnance Test Station. The technique of mixing and casting the syntactic foams parallels that developed in the propellant field, and as such, requires strict adherence to rigid procedures for optimum results.

The selection of a cast aluminum alloy for the personnel and instrumentation spheres, in lieu of a forging, appears to be a reasonable choice since physical tests indicated comparable properties. The major advantage of a casting over a forging, lies in the relative simplicity in developing all the discontinuities associated with a bathysphere, such as increased wall thicknesses for hatches, hydraulic pass-throughs, electric cables, etc. Further, modifications to the basic sphere design can be easily accomplished, since this only entails reworking an inexpensive wooden pattern. Because of the limited requirements associated with most developmental work, castings can be more readily utilized than costly forgings, when contemplating structures of the size and scope of the Moray spheres.

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